Music and movement: Musical instruments and performers

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Abstract

When people sing or play musical instruments, they perform complex and controlled movements to produce particular sequences of sounds. Their body movements serve other functions too – they facilitate coordination with co-performers, communicate expressive nuances to the audience, and support the performer's own engagement with the music. Skilled musicians have refined motor skills and excellent control over the sounds they produce. They are also highly successful at interpreting and synchronizing with the movements made by their co-performers. In this chapter, we discuss key concepts of empirical movement research in music performance, with a focus on 1) sound production and 2) visual communication in ensemble playing. We describe the movements used by skilled musicians to achieve desired sound qualities, and the communicative movements exchanged by ensemble performers to coordinate their intentions. The importance of anticipating the desired effects of performance gestures – an ability that develops with increasing motor skill – is also discussed.

Introduction

Music and movement are intrinsically bound. When we make music, we carry out sequences of controlled movements with the aim of producing certain sounds. Playing the piano, for instance, involves moving your hands and fingers in a way that allows you to press the keys in a specific order. Of course, pianists make many other movements as they play – the arms, head, upper body, legs, and feet are often in near-constant motion. These movements may not be directly involved in producing sound, but they have both technical and communicative functions, shaping the tone that is produced, helping us coordinate with our co-performers if we are playing in a group, and communicating our expressive intentions to the audience.

Movement is tied to music perception just as it is tied to music production. When we experience another person's performance, we hear the sounds that result from that person's movements. Our perception of expression in the sounded performance is shaped by the type and quality of movements used. Our perceptions of performance expression also depend on whether we can see as well as hear the musicians playing. Musicians' body movements – even those movements not directly involved in sound production – communicate a great deal of information (Wanderley, et al., 2005). Body movements help to indicate performers' interpretations of the music, while also giving clues as to their intentions, allowing both audience members and co-performers to predict when the next note is going to come and how it is going to sound.

Thus, both sound and movement are critical means of musical communication. The link between music and movement is particularly significant, since, in most musical genres, movement is required to produce sound, and it is only by carrying out precise and controlled movements that performers can produce sounded music that fits with their intentions. In this chapter, the role of movement as a means of musical communication is discussed. We examine the functions of performers' body movements, with a focus on how these movements are controlled and how they contribute to performers' realization of their expressive intentions. We begin in the next section with a discussion of the methods that can be used to investigate performers' body movements.

Methods for mapping and measuring body movements

Researchers studying musicians' body movements require recording techniques that capture movement information as precisely as possible, while interfering as little as possible with the movements themselves (see Goebl, Dixon, & Schubert, 2014 for a review of movement analysis techniques). Video recording, which is unobtrusive and relatively inexpensive, is often used (e.g. Tsay, 2014; Wanderley, et al., 2005; Williamon & Davidson, 2002). Audio and video recordings can be aligned with high precision, making video recording an effective means of capturing motion that will be analyzed qualitatively (e.g. by categorizing gesture types; relating motion to sounded music) or used for perceptual experiments (e.g. assessing tolerance for audiovisual asynchrony; examining the influence of gesture observation on the perception of sounded music). Some kinematic analysis of body movements in video data is also possible using recently-developed movement tracking and recognition algorithms (Castellano, et al., 2008).

Three-dimensional motion capture systems present an alternative to video recording. Despite some disadvantages – they are expensive, require substantial technical knowledge, and are difficult to transport between performance spaces – they are capable of mapping the trajectories of performers' body joints with very high spatial and temporal precision. Motion capture systems use infrared cameras to track the movement of markers through three-dimensional space. Markers are affixed to specific locations on the performer's body and either reflect light (in the case of passive systems) or emit an infrared signal (in the case of active systems). Active systems use markers that are attached to cables, so passive systems are often preferred in situations where cables would interfere with the performer's movement. However, active systems are better than passive systems at re-identifying markers that reappear after briefly disappearing from the cameras' fields of view (which can happen when, for instance, a moving limb obstructs the line of sight). Passive systems require post-processing to ensure that pre- and post-disappearance trajectories are linked to the same marker.

Data collected via motion capture systems can be used for detailed analyses of body kinematics. Large-scale movements, like instrumentalists' head nods or body sway, as well as small-scale movements, like the motion of pianists' fingers on the keyboard, can be analyzed. As we see in throughout the remainder of this chapter, such fine-grained analyses provide a critical basis for determining the functions of performers' body movements.

Performance gestures: what purpose do they serve?

In the literature on human movement, the term "gesture" is used to describe a body movement that carries meaning (Jensenius et al., 2010; Kendon, 2004; Leman, 2008). A movement does not have to produce a meaningful outcome, such as a sounded word or tone, to constitute a gesture (though sound-producing movements are gestures as well). Rather, it is the movement itself that is meaningful. The musical gestures used in performance include facial expressions, body sway, and head nods, as well as sound-producing movements like the drop of a hand onto piano keys or the sweep of a bow across violin strings.

There has been some debate about whether a movement has to be intentional (i.e. executed deliberately) to count as a gesture, and likewise, whether it is only a gesture if its meaning is understood by observers. In this chapter, the movements of performers that we refer to as "gestures" have only the potential to be correctly interpreted by observers (see Chapter 5.4, this volume). Part of what makes music an artform rather than a systematic transfer of specific information is that performers' gestures, as well as the sounded music they produce, are ambiguous, to a degree, and interpreted in different ways by different people. We also suggest that many of the gestures a performer makes are not themselves intentional. Instead, the performer has an underlying intention to communicate particular ideas, and it is this intention that shapes the gestures that are made, while the performer focuses attention primarily on anticipating the sounds that they aim to produce.

Performance gestures can be grouped into categories according to the functions they fulfill (Dahl et al, 2010):

1. *Sound-producing gestures* are directly involved in producing or modifying sounded tones (e.g., blowing into the mouthpiece of a clarinet).
2. *Sound-facilitating gestures* support the production of sound without producing sound themselves (e.g., changing posture of the body to help in playing at a higher sound level).
3. *Communicative gestures* are those performers direct at others to emphasize their interpretation or help coordinate their playing (e.g., nodding to a co-performer).
4. *Sound-accompanying gestures* are made in response to sounded music (e.g., dancing).

These categories are not intended to be discrete, but rather, overlapping, as most performance gestures serve multiple purposes. When performers are drawn by the sound of the music to tap their feet to the beat, for example, they might be simultaneously responding to the music they hear, supporting the maintenance of a steady tempo in their own performance, and emphasizing the beat structure for the audience. Attempting to segment performers' movements into meaningful units can be a difficult task anyway, since performers are in constant motion. Multiple gestures are often coarticulated (i.e. joined together and overlapping in time; Godøy, 2010); some align precisely with a particular level of the temporal framework in the sounded music, while others align with a different level or do not align with the temporal framework at all (Demos, Chaffin & Kant, 2014). The way a gesture is performed is subject to the influence of other overlapping gestures as a result.

Music performance is therefore a very complex task motorically. Many different movements must be made in parallel, along different timescales, and with high precision. Success on such a task would not be possible if it were necessary to focus attention and deliberately control each movement that had to be made. Instead, music performance research has shown that most sub-tasks proceed automatically, without the performer focusing attention on them or attempting to control them (Palmer, 1997). This raises an interesting question: if performers are not constantly focusing on the execution of their movements, what are they attending to instead? In the next section, we discuss how skilled musicians' focus on anticipating the effects of their actions helps them carry out their expressive intentions successfully.

Controlling performance gestures through anticipation

Skilled musicians report using a mental image of the sound they want to produce to help guide their performance. Their descriptions of a guiding mental image have been supported by empirical research, which suggests that musicians anticipate the effects that they intend their actions to have through a process referred to as anticipatory imagery (Keller, Dalla Bella, & Koch, 2010).

The ability to anticipate the effects of your actions develops as you gain experience in performing those actions and perceiving the consequences that they have on the world (Hommel, 2001). Action-effect associations form in the brain and strengthen with increasing expertise. Student pianists, for example, learn to associate different hand motions on the keyboard with different sound qualities in piano tone. According to theories of internal models, these action-effect associations can activate bidirectionally: via forwards activation, motor commands are provided to incite the performance of an action, while via inverse activation, an expected effect primes the action necessary to achieve it (Jeannerod, 2003). In this way, performers' attention to the expected effects of their actions can enable automatic selection and performance of the movements necessary to achieve those effects.

During expressive performance, musicians must control many aspects of the sound they are producing, including (depending on the constraints of their instruments) pitch, timing, articulation, dynamics, and timbre. People can imagine all of these parameters offline (i.e. not concurrently with performance; Bishop, Bailes & Dean, 2013). Online (i.e. during performance), research has shown that at least pitch, timing, articulation, and dynamics are imagined. Some studies, for instance, have compared expressive performances given in silence (e.g., on a keyboard with the sound turned off) to baseline performances given under normal audio conditions. Pianists maintain expressive parameters such as dynamics and articulation when performing in silence – as well maintaining accuracy in pitch and timing – suggesting that anticipatory imagery guides their movements even when no sound is produced (Bishop, et al., 2013).

Research on perceptual-motor expertise suggests that experts perform better when attending to an anticipatory image than when focusing on movement execution. Novices, in contrast, perform better when they focus on executing movements. This contrast was observed in a study with expert and novice soccer players: experts performed better on a dribbling task under dual-task conditions (while simultaneously monitoring a stream of sounded words for a particular target) than under skill-focused conditions (while monitoring their foot movements and indicating verbally at regular intervals which part of their foot had last touched the ball). Thus, if the unrelated word-monitoring task interfered with experts' dribbling performance, the degree of interference was less than that caused by attending to foot movements. Novices showed the opposite results, performing better under skill-focused conditions than under dual-task conditions (Beilock, et al., 2002).

The optimal method for performance may therefore differ between experts, for whom anticipatory imagery is strong and movements are largely automatized, and novices, for whom anticipatory imagery is less well-developed and movements require deliberate control. It is important to acknowledge, however, that attention is constantly in flux during performance, and usually distributed among a number of cognitive processes. Performers' awareness of their own body gestures changes from moment to moment, as does the degree of deliberate control that they exert over those gestures (Toner & Moran, 2014). At times, it is beneficial for experts to direct their attention towards the execution of their gestures; for instance, when refining movements during practice.

In the next sections, we focus on how anticipation underlies the use of two types of performance gestures: 1) sound-producing gestures and 2) communicative gestures that help performers maintain interpersonal coordination when playing together. The aim of the first section is to illustrate how performers' control over their technical movements helps them achieve their expressive intentions. The aim of the second section is to show how performance gestures help ensemble musicians anticipate each other's actions and coordinate their playing.

Focus point: Playing technique under the magnifier

Sound-producing gestures are the movements that enable musicians to create sounds on their musical instruments. They are goal-directed, in that their aim is to generate or modify sound in a refined and controlled way. These gestures vary greatly with the particular instrument played, as tone production depends on the properties of instruments' acoustical systems and the control parameters available.

For example, on bowed string instruments, different movements are performed by the left and right hand: the right moves the bow against the strings to generate sound, while the left controls pitch and vibrato by pressing against the fingerboard. Left and right hand movements have to be coordinated with high precision (Baader, Kazennikov, & Wiesendanger, 2005). On keyboard instruments, in contrast, the two hands – even the individual fingers – produce different sounds independently, and, therefore, may exhibit different degrees of coordination. Musicians refer to these movements and their acquisition and development generally as playing technique.

Individualism in expert playing technique

As musicians acquire their personal movement strategies – via a learning process that takes many years of practice (Krampe & Ericsson, 1996; see Chapters 4.5 and 4.6, this volume) – they gain the ability to repeat movement patterns with high reliability. At the same time, their playing gestures may differ increasingly from those of other musicians, despite generating sometimes identical sounds. Looking at finger-tip kinematics of skilled pianists, Dalla Bella and Palmer (2011) were able to train a neural-network classifier to successfully recognise a particular pianist just by finger velocity and acceleration patterns, a result recently confirmed with skilled flute players (Albrecht et al, 2014).

Individual movement strategies may also be related to timing quality and maximum tempo. Goebl and Palmer (2013) measured the entire kinematic chain from the fingertip to the forearm of the right hands of a dozen skilled pianists, who were asked to play a short melody in as many tempo conditions as possible, starting from a medium tempo and increasing to fast tempi. The pianist who was able to perform most precisely and accurately across tempo conditions, and who was also the only participant able to perform in the fastest tempo condition (16 tones per second), showed the most efficient keystrokes, based on an efficiency measure that combines all joint angle trajectories during a single keystroke. Conversely, pianists with keystrokes of lower efficiency showed performances that were less precise, and had lower maximum tempi. These findings suggest that despite a wide range of possible ways of executing sound-producing movements (degrees of freedom problem in motor control; Kay, Turvey, & Meijer, 2003), there are certain movement characteristics that better support fast, precise and accurate performance. Musicians have to find the optimal movement strategies that best fit the desired sounding goal.

The properties of sound-producing movements change systematically with performance tempo. At slow tempi, the gestures are usually well separated from each other (e.g., with hovering phases in between active keystrokes on the piano, Goebl and Palmer, 2009). As the tempo increases, the movement duration takes larger parts of the inter-onset intervals, and those movements start to overlap and form one compound movement (Kay et al, 2003). Pianists raise their fingers higher above the keyboard at faster tempi, which is in contrast to recommendations of educators to strive to play as closely to the keys as possible (Bernstein, 1981). Similar observations were made with clarinetists who raise their fingers higher (Palmer, Koopmans, Loehr & Carter, 2009), even though educators recommend keeping the fingers close to the keys. However, clarinetists also use less force on the keys at faster tempi (Hofmann & Goebl, submitted), which is again in line with such recommendations.

Different ways of executing sound-producing movements usually lead to differences in the sounds produced. On the piano, the main acoustical parameter of dynamics is shaped by the speed with which the hammer hits the strings. It has long been believed that piano sounds produced with identical hammer velocities sound identical, even if they have been played with entirely different keystroke movements. Recent research, however, has shown that different ways of touching piano keys (e.g., pressing or striking them; see Furuya & Kinoshita, 2008) produce differences in piano timbre that are well-discriminated by listeners, even though hammer velocities are identical (Goebl, Bresin, & Fujinaga 2014). Conversely, there are systematic modifications of sound-producing movements that do not affect the sound; for example, clarinet keys have to be closed to modify the pitch, making any additional finger force against the keys superfluous. However, clarinetists' finger forces on the ring keys of a clarinet clearly vary: clarinetists press harder at slower tempi, at higher registers, at louder dynamics, and when they perform with more expression (Hofmann & Goebl, submitted).

Sound-producing movements are optimized in expert performers. Experts usually show a more economical approach in their movement properties than do student-level or amateur musicians. For example, professional pianists exhibit smaller angular finger joint activity and lower muscular load while performing fast alternating tone sequences than do amateur pianists (Furuya et al, 2011). Professional players also show lower peak finger forces compared to student players on the clarinet (Hofmann & Goebl, submitted) and on the piano (Parlitz, Peschel, & Altenmüller, 1998). However, professional pianists use more covariation between fingers that possess an innate connectivity between them, such as the ring and little finger, while amateurs work against those conditions (Winges & Furuya, 2014).

Motor feedback from sound-producing gestures

Sound-producing movements also yield non-auditory sensory feedback that facilitates control of the produced sequences (Palmer, 2013). For example, a kinematic landmark occurs when the finger touches the piano key surface during a keystroke, reflected in a large change in the acceleration trajectory that may be used as tactile information by the pianist to control the timing of the sequence. These finger-key landmarks occur more often and are more pronounced when pianists play faster and louder (Goebl & Palmer, 2008). Moreover, the magnitude of these landmarks is related to the timing accuracy of the subsequent event, suggesting that pianists use this tactile feedback to improve their timing control.

This finding was replicated in a kinematic analysis of skilled clarinet performances (Palmer, Koopmans, Loehr & Carter, 2009). However, the fingers control timing on the clarinet only in legato articulation. In other articulation types (portato, staccato), the tongue controls timing together with the fingers, or sometimes independently of the fingers (tone repetitions). In a study that investigated the coordination of tongue and finger forces on the clarinet, Hofmann and Goebl (submitted) found that timing control of the tongue alone was more precise that timing control of fingers alone. Combined tongue and finger control enabled well-stabilized and accurate timing.

Focus point: Visual communication for ensemble synchronization

Ensemble musicians must align their individual interpretations to produce a coherent joint performance. Each ensemble member maintains an image of how his or her own part should be performed, as during solo performance; however, it is also important that all members share a joint goal image of what they want to achieve as a group (Loehr, et al., 2013). To maintain a shared goal image, ensemble musicians must be able to interpret their co-performers' intentions. Performers thus try to be as predictable as possible to each other without sacrificing the expressiveness of their performance. Visual communication can be an important means of exchanging information about each other's interpretation and improving predictability.

Predicting the outcomes of observed gestures: when is it useful?

For the most part, ensemble musicians can predict their co-performers' intentions based purely on the sound of their playing. Depending on the structure of the music and how strictly the ensemble follows a steady beat, visual contact between performers may not even be needed for a coherent performance to be achieved (Ragert, Schroeder, & Keller, 2013). These expectations develop automatically as a result of familiarity with the musical genre (Ockelford, 2006).

In less predictable musical contexts, visual communication becomes critical. During improvisation, or when playing notated music with large temporal fluctuations, long pauses, or abrupt changes in tempo, it can be more difficult to predict co-performers' upcoming actions based on the sound of their playing alone (Kawase, 2013). Ensemble musicians then attend to their co-performers' body movements for clarification of their intentions.

A study of ours investigated pianists' use of visual communication across different structural contexts (Bishop & Goebl, 2015). Recordings were made of skilled pianists and violinists performing the primo part to three piano duets (with live accompaniment, which was recorded separately). The duets that we selected included some potential challenges for synchronization (e.g., a slow, free tempo; long pauses). We assessed pianists' synchronization with these recordings as their access to audio and visual communication channels was manipulated: in an audio-visual condition, pianists could see and hear the primo playing, while in an audio-only condition they could hear but not see the primo, and in a visual-only condition they could see the primo but not hear his or her playing.

Pianists were little affected by the removal of incoming audio, with synchronization equally precise in audio-visual and audio-only conditions. Synchronization was worse in the visual-only condition, indicating that accompanists rely primarily on incoming audio to coordinate their playing with that of a soloist. In audio-visual and audio-only conditions, asynchronies were larger following phrases that ended on a fermata than they were mid-phrase, while in visual-only conditions, asynchronies were larger mid-phrase than they were at these phrase boundaries. This finding suggests that the gestures given at re-entry points (i.e., following long pauses) are particularly meaningful and communicate performers' intentions more effectively than do the gestures given elsewhere in the piece. Performers probably also attend more closely to each other's gestures at re-entry points, since timing is imprecisely specified by the score and they are less certain of each other's intentions.

Communicating the concept of time through performance gestures

Ensemble musicians aim to coordinate a number of parameters, but paramount among these is timing. How is information about piece timing encoded into performers' gestures? A few studies investigating different types of musical gestures have examined which gesture features indicate beat position to observers. In one study, people were asked to synchronize key-presses with conductor gestures (Luck & Sloboda, 2009). Observers used either peak velocity or peak acceleration as a reference for beat position, depending on the size of the radius of curvature in the baton movements. In another study, people judged the audiovisual synchrony between sounded rhythms and point-light representations of a bouncing human figure (Su, 2014). These observers used peak velocity as a reference for beat position in the bouncing movements.

Thus, the gesture features that indicate beat position seem to be temporal rather than spatial, even when the gestures follow a repetitive, predictable spatial trajectory, as with the bouncing movements. These findings suggest that the processes underlying visual beat perception are not specific to individual gesture types. Different gestures may follow very different spatial trajectories, but that should not impede on beat perception if the position of the beat is determined by temporal features.

A recent study of ours examined the gestures that instrumentalists use to cue each other at the beginnings of pieces (Bishop & Goebl, submitted). Visual communication is particularly important at the start of pieces, since there is no prior sound to help performers determine when their notes should be played. Cueing-in gestures are usually given by a designated leader (e.g. the first violinist in a string quartet) and need to communicate the temporal placement of the first beat as well as the starting tempo of the piece.

Piano and violin duos played through short pieces as their head movements were tracked with Kinect sensors and accelerometers. On each trial, one performer or the other was designated the leader and asked to cue their partner in, without speaking, at a tempo selected by the experimenters. Both leaders' and followers' first note onsets coincided with instances of peak head velocity in the forwards direction, suggesting that head velocity acts as a reference for beat position. Periodicity in head acceleration related to piece tempo. Thus, information about both beat position and tempo seem to be encoded in the temporal features of instrumentalists' cueing-in gestures.

Interpreting incoming visual signals

As described earlier in this chapter, learned associations between actions and their perceptual consequences enable performers to anticipate what the effects of their own actions will be. These same associations are activated when people see others performing those actions, allowing observers to anticipate the effects of others' actions (Cross, et al., 2009). This process, termed action simulation, is thought to underlie the prediction of both observed and sounded action outcomes (Jeannerod, 2003).

In support of this theory, people are particularly successful at predicting patterns of movement that are similar to those they would perform themselves. For example, pianists synchronize more precisely when accompanying recordings of their own performances than when accompanying recordings of others' performances (Keller, Knoblich, & Repp, 2007). People are also particularly successful at predicting movements that they have prior experience in performing themselves. Extensive visual exposure to particular movements also improves prediction, but to a lesser extent (Wöllner & Cañal-Bruland, 2010).

Our research has tested how instrument-specific performance expertise affects prediction and synchronization in music ensembles. Do pianists synchronize more successfully with other pianists than with string players, and do string players synchronize more successfully with each other than with pianists? In our study investigating ensemble musicians' cueing-in gestures (Bishop & Goebl, submitted; discussed above), synchronization was worse for piano-violin duos than for either piano-piano or violin-violin duos (who performed similarly to each other). On average, asynchronies were highest for the first note of a piece and improved rapidly across the next few notes. This pattern was observed for all instrument pairings, but for piano-violin duos, the asynchrony for the first note was greater than for the other groups, and the improvement across the first three notes was less. Thus, the musicians in this study benefitted from playing with a same-instrument partner both at the first note (which required synchronizing with an observed gesture) and through the body of the passages (which required effective use of combined audio and visual cues).

Conclusions

This chapter has focused on the movements involved in producing, shaping, and coordinating sounds during music performance. We describe the sound-producing gestures used by different varieties of instrumentalists, as well as the features of communicative gestures that musicians use to indicate their intended timing to their co-performers. We also discuss how a distal focus, directed to the expected outcome of sound-producing gestures, can benefit skilled performance, and we show how anticipation of others' movements enables coordination between ensemble performers.

Though the audience's perspective of performance gestures was not the focus here, both the observation of performance gestures and a familiarity with the sorts of gesture that underlie sound-production shape the audience's experience. At times, the audience's perception of performance gestures can even sway their perception of the sounded music (Tsay, 2014). Movement underlies most of the music that people experience on a daily basis. However, we might also wonder about music that has been made without the use of the gestures that have traditionally been required to produce musical sound. Such cases can arise when a human performer is replaced by a computer system, when human musical performances are recorded, then altered to include acoustic effects that could not have been produced by performing on an existing instrument, or when computer music is designed to incorporate environmental or digitally-constructed sounds that listeners would not attribute to human movements.

An aim of future research should be to determine how divorcing music from sound-producing and communicative movements affects the experience of both performers and listeners. For example, do musicians have more difficulty coordinating with computer co-performers than with human co-performers? How are listeners' perceptions of expression in sounded music affected by the inclusion of sounds that are not associated with physical movements?

The link between music and movement has long been acknowledged, and as discussed in this chapter, researchers continue assessing and defining the movements involved in producing sounded music. At the same time, recent developments in machine learning and audio engineering are expanding the opportunities available for creating and/or performing music that does not draw on human movement. Such developments provide researchers with valuable new genres of material to consider. Systematic study of the forms of music that draw little or not at all on human movement, alongside continued study of performance gestures, may enable an improved understanding of how critically bound music and movement are.

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